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Editor's Choice – First Results of the Covered Endovascular Reconstruction of the Aortic Bifurcation (CERAB) Technique for Aortoiliac Occlusive Disease

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WHAT THIS PAPER ADDS

The study is an evaluation of the first (and largest) patient cohort, treated with a new technique called the "Covered Endovascular Reconstruction of the Aortic Bifurcation," the CERAB technique. The study shows the safety and excellent patency of this technique when treating aortoiliac arterial occlusive disease. These first promising results are an indicator for a potential shift from open surgical bypass grafting to endovascular treatment for patients suffering from disabling intermittent claudication or critical limb ischemia.

Objective: In this study the first results are presented of a new endovascular technique using covered stents to reconstruct the aortic bifurcation in patients with aortoiliac occlusive disease. With the "Covered Endovascular Reconstruction of the Aortic Bifurcation" (CERAB) technique, the anatomy and physiology of the aortic bifurcation is mimicked.

Material and methods: Between 2009 and March 2014, 103 patients (51 male, 52 female) suffering from obstructive lesions at the level of the aortic bifurcation were treated with CERAB in two clinics. The median age was 61 years (range 36–85 years). Lesion morphology was evaluated by CT angiography. Six TASC-II B lesions, nine TASC-II C lesions, and 88 TASC-II D lesions were treated. Follow up was a median 12 months (range 0–49 months) and consisted of clinical examination, ankle brachial indices, and duplex ultrasound examination.

Results: Technical success was obtained in 98 procedures (95.1%). In five cases lesions could not be recanalized. Primary patency was 87.3% at 1 year and 82.3% at 2 years, while secondary patency was 95.0% at 1 year and 95.0% at 2 years. Mean ankle brachial indices improved significantly from 0.64 $\pm$ 0.21 before to 0.91 $\pm$ 014, after the procedure ($p < .001$). The overall 30 day complication rate was 23.3%, including 22 minor complications and two major complications (1.9%). There was no 30 day mortality. Median hospital stay was 2 days (range 1–16 days).

Conclusions: The CERAB technique appears to be a safe and feasible alternative to open surgical reconstruction of the aortic bifurcation in complex occlusive disease. Comparative studies with the current gold standards are indicated.

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INTRODUCTION

According to the Trans-Atlantic Inter-society Consensus document (TASC-II), surgical reconstruction, typically by means of aorto-bi-iliac bypass grafting, is the treatment of choice for extensive aortoiliac occlusive lesions, classified as TASC-II D, and should also be considered in bilateral occlusion of the common iliac arteries (TASC-II C). This is the consequence of the good long-term patency rates after surgical reconstruction. Surgery, however, is associated with both early and late morbidity and peri-operative mortality. Therefore, comorbidities should be taken into consideration when planning a reconstruction for aortoiliac occlusive disease (AIOD).[1]

In 1991 the kissing stent technique was introduced as an endovascular treatment alternative for bilateral aortoiliac occlusive disease. In this technique, two stents are placed simultaneously in the common iliac arteries, with an overlap in the distal aorta.[2,3] Reported technical success rates varied between 89% and 100% with a 1 year primary patency rate between 76% and 98% with the use of bare

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metal stents (BMS) in TASC-II C and D lesions.[4] Variations in patient and lesion characteristics and techniques used may have caused the variation in outcome.

Covered stents may increase patency rates in extensive disease, as shown by the COBEST trial and confirmed in various case series.[5–9] The COBEST trial showed that covered balloon expandable stents (CBES) have a superior primary patency rate and clinical improvement outcome at 24 months when compared with bare metal stents.[9] In addition CBES may immediately treat or reduce the risk of procedural complications such as dissection, perforation, and embolization, with potential for reducing morbidity and mortality.

The Covered Endovascular Reconstruction of the Aortic Bifurcation (CERAB) technique was developed in an attempt to overcome the anatomical and physiological disadvantages of kissing stents.[10] Patency rates of kissing stents may be influenced by geometrical factors such as radial mismatch, defined as the perfused dead lumen space around the stents, protrusion mismatch defined as the overlap distance of the stents in the distal aorta, and stent conformation. All these factors may cause flow disturbances leading to re-circulation, turbulence, and stasis of blood, which in turn, may cause thrombus formation and intimal neohyperplasia.[11–14] A recent in vitro geometrical study showed superior stent conformation and lower radial mismatch in the CERAB configuration when compared with the kissing stent configuration.[15] In the present study the first clinical results of the CERAB technique are presented.

METHODS

Patients

Consecutive patients treated between February 2009 and March 2014 using the CERAB technique were prospectively gathered in a database and retrospectively analyzed. Permission was obtained from the institutional review board.

Patients were treated in two hospitals: Rijnstate Hospital Arnhem, the Netherlands and ZNA Clinics, Antwerp, Belgium. Patients with acute limb ischemia were excluded from this analysis, as were patients treated with chimney configurations. Anatomical suitability for the CERAB procedure was assessed using computed tomography (CT) angiography. In all patients cardiovascular risk reduction was performed, including prescription of anti-platelet therapy (in the absence of anti-coagulant therapy) and statins if indicated. All patients treated for intermittent claudication were initially treated with (supervised) walking exercise and considered for treatment only if symptoms persisted and were disabling.

Demographics, clinical status, medical history, and procedural aspects were noted. The clinical status was assessed using the Rutherford Classification for chronic ischemia.[16] Comorbidity was scored according to the Society for Vascular Surgery and American Association for Vascular Surgery medical comorbidity scoring system.[17]

CT images were reviewed and scored according to the TASC-II criteria.[1] Routine follow up included clinical assessment, ankle brachial index (ABI) measurements, and duplex ultrasound scans at 1, 3, 6, and 12 months, and annually thereafter. Complications and additional treatments were registered in the hospital files.

Technique

Details of the CERAB technique have been described previously.[10] Briefly, patients were treated either in a hybrid operating theater or in a catheterization laboratory. Two introducer sheaths were introduced (9Fr and 7Fr) into the common femoral arteries, either percutaneously or by surgical cut down. Heparin (5,000 units) was administered to all patients. The occlusive lesion was then passed, either subintimal or endoluminal, using regular catheters (Super Torque, Cordis Corporation, Miami Lakes, FL) and a Terumo wire (Terumo Medical Corporation, Elkton, MD). After gaining re-entry into the lumen of the aorta, angiography confirmed proper positioning for those with a subintimal passage (Fig. 1A). A 12 mm V12 LD balloon expandable ePTFE covered stent (Atrium Medical, Maquet Getinge Group, Hudson, NH) was expanded in the distal aorta approximately 20 mm above the bifurcation through the 9 Fr sheath. The proximal 2/3 part of the aortic stent was flared with a larger balloon, usually 16 mm, thereby creating a funnel shaped covered stent. Subsequently, two covered CBES were placed proximally in the distal 1/3 of the aortic stent (consequently the part of the covered stent that was still 12 mm in diameter) and distally into the common iliac arteries and were deployed simultaneously (Fig. 1B). Typically, two V12 balloon expandable ePTFE covered stents (Atrium Medical, Maquet Getinge Group, Hudson, NH) with a diameter of 8 mm were used, with these two stents creating a tight connection with the first aortic stent, thereby creating the new aortic bifurcation (Fig. 1C). When required, distal extensions were added. The sheaths were removed from the common femoral artery and the puncture sites were closed, usually using a closure device (Angio-Seal, St. Jude Medical, St. Paul, MN or Perclose/Starclose, Abbott Vascular, Abbott Park, IL) or sutured in cases of open introduction. Concomitant endarterectomy of the femoral artery or external iliac artery was performed in cases of multilevel disease. Patients received standard statin treatment and dual anti-platelets for 6 months followed by mono-therapy, unless oral anti-coagulation was indicated for other reasons.

Definitions

The primary outcome measure was 1 year primary patency. Secondary outcomes were technical success, length of hospital stay, morbidity, mortality, clinical improvement, secondary patency, and limb salvage.

Classifications were used according to the reporting standards.[16,18] Technical success was defined as stent placement restoring blood flow with $<30\%$ residual stenosis. Primary patency was defined as uninterrupted patency

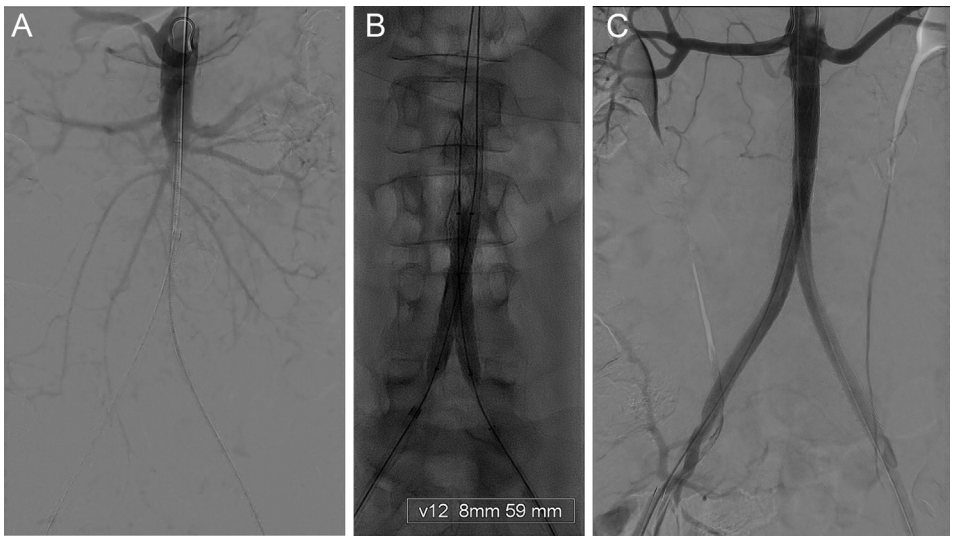


Figure 1. (A) Angiography of a 52 year old female patient with disabling intermittent claudication showing total occlusion of the distal aorta and both iliac arteries. (B) Both iliac stents are simultaneously deployed, with 2 cm overlap into the funnel shaped aortic stent, thereby creating a tight connection. (C) Control angiography showing the CERAB configuration in place, thereby creating a new aortic bifurcation.

in the absence of re-stenosis or occlusion, without any procedures performed on the vessel or stent. Secondary patency was defined as patency achieved by all procedures aimed at recanalizing an occluded CBES, thereby preserving the endograft. Freedom from target lesion revascularization (TLR) was defined as an open endograft without procedures performed for re-stenosis or occlusion leading to symptoms requiring an intervention. Criteria for re-intervention included clinical deterioration based on occlusion or stenosis, or stent collapse.

Clinical improvement was defined as a hemodynamic improvement with and increase of at least 0.10 in ABI, combined with a symptomatic improvement of at least one Rutherford category. Re-stenosis was defined as a lesion with a peak systolic value (PSV) ratio $\geq$2.5 as measured in the endograft and proximal or distal to the endograft or an angiographic diameter reduction of $>$50%.[18,19]

Limb salvage rate was defined as all patients without above ankle amputations. Minor complications were defined as those that were only temporary leading to impairment, whereas major complications were defined by permanent damage or death.

Statistical analysis

Variables were expressed as mean $\pm$ one standard deviation (SD) in case of normal distribution, or median plus range in other distributions. In all patients the mean ABI of both legs was calculated to compare pre- and post-procedural ABI with paired *t* tests.

Patency and limb salvage rates were estimated using the Kaplan-Meier survival analysis on a per patient basis. To test for survival differences, analyses with the log-rank (Mantel-Cox), or the generalized Wilcoxon (Breslow) tests were used. Probability values given are based on two sided analyses of test results. A significance level of 5% was used. Statistical analysis was performed with SPSS version 19.0 (Statistical Package for the Social Sciences, Inc., Chicago, IL).

RESULTS

One hundred and three patients (51 male, 52 female) underwent a CERAB procedure for chronic ischemia during the study period and were included in this study. Five other patients were treated with a CERAB configuration for acute ischemia in this period but were excluded from this analysis, as were five patients who were treated with chimney grafts in the inferior mesenteric artery or renal artery in combination with a CERAB. During the study period 32 other patients were treated with a surgical bifurcation prosthesis. The median age of the study group was 61 years (range 36—85 years). Patient characteristics and co-morbidities are listed in Table 1.

The indication for treatment was disabling claudication in 64 patients (62.1%) and critical limb ischemia in 38 patients (36.9%) (Table 1). One patient was classified as Rutherford Category 1. He was treated for an aorto-bi-femoral bypass at risk for occlusion because of subtotal stenosis at the proximal anastomosis of this bypass. The median follow up was 12 months (range 0—49 months). There was no 30 day mortality, but eight patients died during follow up. Six patients died as a result of non-procedure related causes (Table 2), and in the other two patients the cause of death was unknown. Duplex follow up at 6 months was available for 74 patients, at 1 year for 52 patients, and at 2 years for 29 patients.

In 69 patients (67.0%) this was the first procedure performed in the aortoiliac segment, 26 patients (25.2%) had previously undergone endovascular procedures in this segment, including stent placements in 17 patients. Eight

Table 1. Patient characteristics of patients treated with CERAB.

	N	%
Rutherford Category for chronic ischemia[16]:		
1 mild intermittent claudication, walking distance unlimited	1	1.0
2 moderate claudication, walking distance >200 m	0	0
3 severe claudication, walking distance <200 m	64	62.1
4 ischemic rest pain	20	19.4
5 focal tissue loss	17	16.5
6 diffuse gangrene	1	1.0
ASA score		
1	0	0
2	69	67.0
3	27	26.2
4	7	6.8
Tobacco use		
Never, >10 years ago	11	10.7
No, but <10 years ago	12	11.7
Yes < 20/day	45	43.7
Yes > 20/day	32	31.1
Unknown	3	2.9
Diabetes mellitus		
No	71	68.9
Adult, dietary or oral medication controlled	15	14.6
Adult, insulin dependent	14	13.6
Juvenile diabetes	0	0
Unknown	3	2.9
Hypertension		
No	22	21.4
Treated by single drug	37	35.9
Treated by two drugs	30	29.1
Treated by three drugs	11	10.7
Unknown	3	2.9
Hyperlipidemia		
Normal lipids	3	2.9
Mildly elevated, dietary control	12	11.7
Treated with drugs	79	76.7
Unknown	9	8.7
Cardiac disease		
Asymptomatic	58	56.3
Non-recent myocardial infarction (MI) (>6 mo) asymptomatic MI on EKG (electrocardiogram)	26	25.2
Stable angina pectoris, arrhythmias, treatable heart failure	10	9.7
Unstable angina pectoris, recent MI (<6 mo)	7	6.8
Unknown	2	1.9
Pulmonary disease		
Asymptomatic	57	55.3
Mild dyspnea	25	24.3
Moderate dyspnea	21	20.4
O_2 dependent, pulmonary hypertension	0	0
Carotid disease		
No disease	84	81.6
Asymptomatic, but sign of disease	13	12.6
TIA/stroke without temporary deficit	3	2.9
TIA/stroke with permanent deficit	2	1.9
Unknown	1	1.0
Renal disease		
No	84	81.6
GFR 30–50 mL/min	15	14.6
GFR 15–30 mL/min	1	1.0
GFR < 15 mL/min or renal transplant	2	1.9
Unknown	1	1.0

ASA = American Society of Anesthesiologists physical status classification system; GFR = glomerular filtration rate; mo = months; TIA = transient ischemic attack.

patients (7.8%) had earlier surgical reconstructions, including four aorto-bi-iliac bypasses and two aorto-bi-femoral bypasses. The lesion characteristics are shown in Table 3. Most patients were treated for TASC-II D lesions.

Procedural outcome

Technical success was achieved in 98 patients (95.1%). Reasons for technical failure included three cases in which the guidewire could not be passed because of heavily calcified lesions, in one procedure the guidewire could be advanced, but the sheath could not pass the lesion and in one case re-entry into the lumen could not be achieved. In two of these patients a surgical bypass was constructed by means of an aorto-bi-iliac bypass and an ilio-femoral crossover bypass. In another patient, a second attempt was successfully performed (with growing experience) 2 years after the first procedure. The fourth patient, suffering from focal tissue loss, died 48 days after the attempt and before a secondary treatment could be performed.

Seventy-seven procedures (74.0%) were performed percutaneously, and 27 (26.0%) were performed by surgical cut down (18 one site, 9 both sites). In 21 of them the procedure was combined with an endarterectomy of the common femoral artery and/or distal external iliac artery. In five patients an additional PTA was performed in the external iliac arteries, in one patient followed by stent placement. In one case thrombectomy of an occluded limb of a bi-femoral bypass was performed. In one patient the femoral artery occluded during the procedure, with resolution after thrombectomy.

In 60.6% the CERAB configuration consisted of a 12 mm aortic stent either 61 mm ($N = 22$) or 41 mm ($N = 38$) in length and two 8 × 59 mm iliac stents. In 65.7% of the successful procedures the CERAB was completed with the use of three covered stents, as the technique was initially

Table 2. Cause of death during follow up of patients treated with CERAB.

Pulmonary	$N = 1$	36 days after procedure
Cardiac	$N = 2$	48 and 62 days, respectively after procedure
Malignancy	$N = 2$	235 and 286 days, respectively after procedure
Bowel ischemia	$N = 1$	125 days after procedure
Unknown	$N = 2$	35 and 113 days, respectively after procedure

described. The remainder required distal extensions to cover the entire diseased segment. Stent specifications are listed in Table 3.

Procedural complications included 10 dissections, of which six were treated with balloon angioplasty alone and three with an additional stent. One dissection was left untreated as it was not flow limiting (Table 4). There were two iliac artery ruptures. One was covered by CERAB itself and the other with a self expanding covered stent. In one case, already mentioned above, thrombus formation occurred for which a thrombectomy was performed. In two early cases a stent dislodged from the balloon. In one the dislodged stent was placed in the external iliac artery and in the other it was used as an additional proximal stent in the aorta. The overall procedural complication rate was 14.6%. All complications, except the surgical thrombectomy, were resolved endovascularly and did not lead to any permanent deficit.

In three patients a patent internal iliac artery was intentionally occluded to treat concurrent occlusive disease of the external iliac artery. In two patients the contralateral internal iliac artery remained patent and in the third patient it was already occluded.

Table 3. Lesion characteristics and stent specifications of patients treated with CERAB.

TASC-II*			
B		6 (5.8%)	
C		9 (8.7%)	
D		88 (85.4%)	
Outflow vessels		Right	Left
External iliac artery	Open; with stenosis; occluded	66;27;8	73;23;5
Internal iliac artery	Open; with stenosis; occluded	61;26;14	59;26;16
Superficial femoral artery	Open; with stenosis; occluded	67;31;3	70;28;3
Deep femoral artery	Open; with stenosis; occluded	90;11;0	92;9;0
Aortic stent length (mm)			
29		5 (5.1%)	
38		1 (1.0%)	
41		64 (64.6%)	
61		28 (28.2%)	
Unknown		1 (1.0%)	
Aortic stent diameter (mm)			
8		1 (1.0%)	
12		95 (96.0%)	
14		2 (2.0%)	
16		1 (1.0%)	
		Right	Left
Iliac artery stent length (mm)			
38		17 (17.1%)	14 (14.1%)
41		1 (1.0%)	2 (2.0%)
59		80 (80.1%)	83 (83.8%)
61		1 (1.0%)	0
Iliac artery stent diameter (mm)			
6		4 (4.0%)	5 (5.1%)
7		2 (2.0%)	3 (3.0%)
8		88 (88.9%)	85 (85.9%)
9		1 (1.0%)	2 (2.0%)
10		3 (3.0%)	3 (3.0%)
12		1 (1.0%)	1 (1.0%)
Number of stents used			
3		65 (65.7%)	
4		19 (19.2%)	
5		15 (15.2%)	

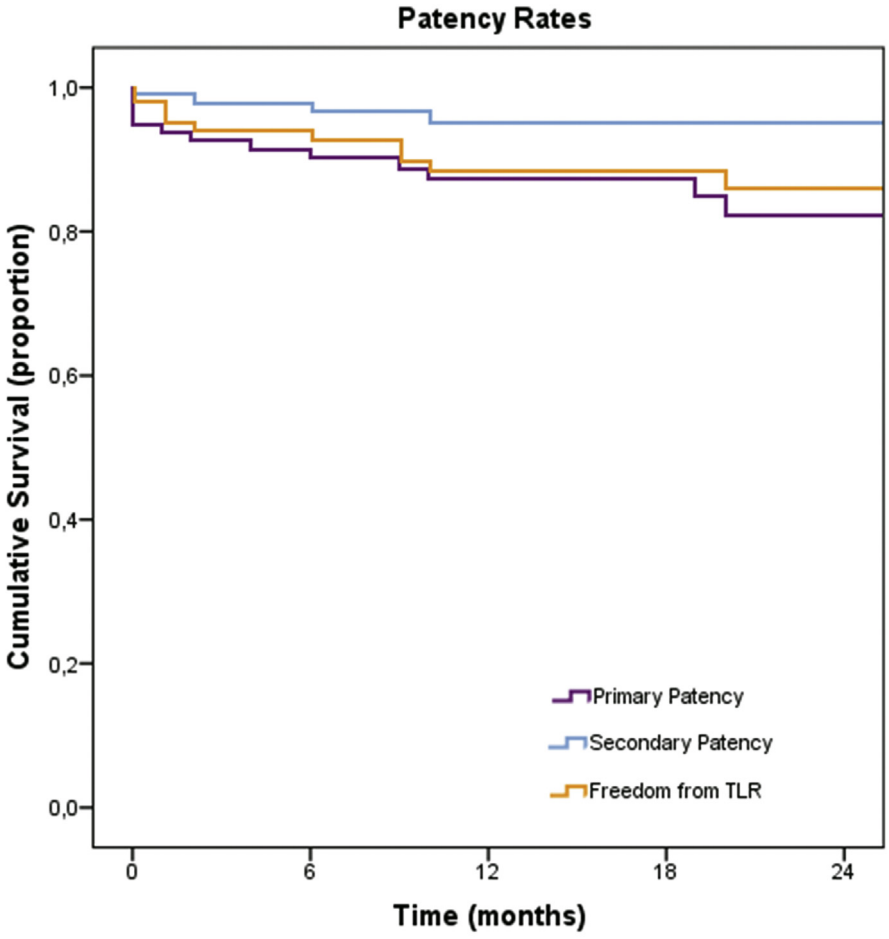
TASC-II = Classification of Inter-Society Consensus for the Management of Peripheral Arterial Disease (TASC II).

Clinical outcome

Thirty day post procedural complications are listed in Table 4. There were 22 minor complications and two major complications. Minor complications included 16 groin hematomas, which were left untreated. There were two pseudo-aneurysms treated with thrombin injection and compression bandage, respectively. There was one re-bleeding which was conservatively treated with a compression bandage. One patient developed atrial fibrillation treated medically. During the post-operative course two patients developed fever of unknown origin and both were treated with antibiotics. Major complications included one patient with deterioration of chronic renal insufficiency after the procedure. The calculated glomerular filtration rate decreased from 53 to 36 mL/min/1.73 m^2. Eventually, this patient required permanent dialysis 1 year after the procedure. One patient developed a bilateral pneumonia and died 5 weeks after the procedure. The 30 day overall complication rate was 23.3%, the major complication rate was 1.9%, and the 30 day mortality was 0%.

Table 4. Complications during CERAB procedure and during first 30 post-procedural days.

Procedural	N	Severity
Dissection	10	Treated in same procedure, not leading to impairment
Rupture/bleeding	2	Treated in same procedure, not leading to impairment
Dislocation stent	2	Treated in same procedure, not leading to impairment
Thrombus formation	1	Treated in same procedure, not leading to impairment
Post-procedural (30 days)		
Minor complications		
Groin hematoma	16	No influence on health, one patient temporary impaired
Re-bleed	1	Temporary impairment, no intervention
False aneurysm	2	One recovered after intervention, other patient temporary impaired
Fever unknown cause	2	Temporary impairment
Atrial fibrillation	1	Temporary impairment
Major complications		
Kidney failure	1	Permanent damage
Pneumonia	1	Leading to death at the 36th post-procedural day



Primary patency					
No at Risk	98	70	49	35	28
Patency (%)	100	90.2	87.3	87.3	82.3
SE (%)	0	3.1	3.6	3.6	4.9
Secondary patency					
No at Risk	98	73	52	37	29
Patency (%)	100	96.5	95.0	95.0	95.0
SE (%)	0	2.0	2.5	2.5	2.5
Freedom from TLR					
No at Risk	98	71	50	35	29
Patency (%)	100	92.4	88.2	88.2	85.6
SE (%)	0	2.8	3.6	3.6	4.3

Figure 2. Kaplan-Meier survival analysis showing patency curves of patients treated with CERAB.

Median duration of admission was 2 days (range 1—16 days). Twenty-one patients (20.3%) were admitted to an intensive care unit for the median duration of 1 day (range 1—3 days).

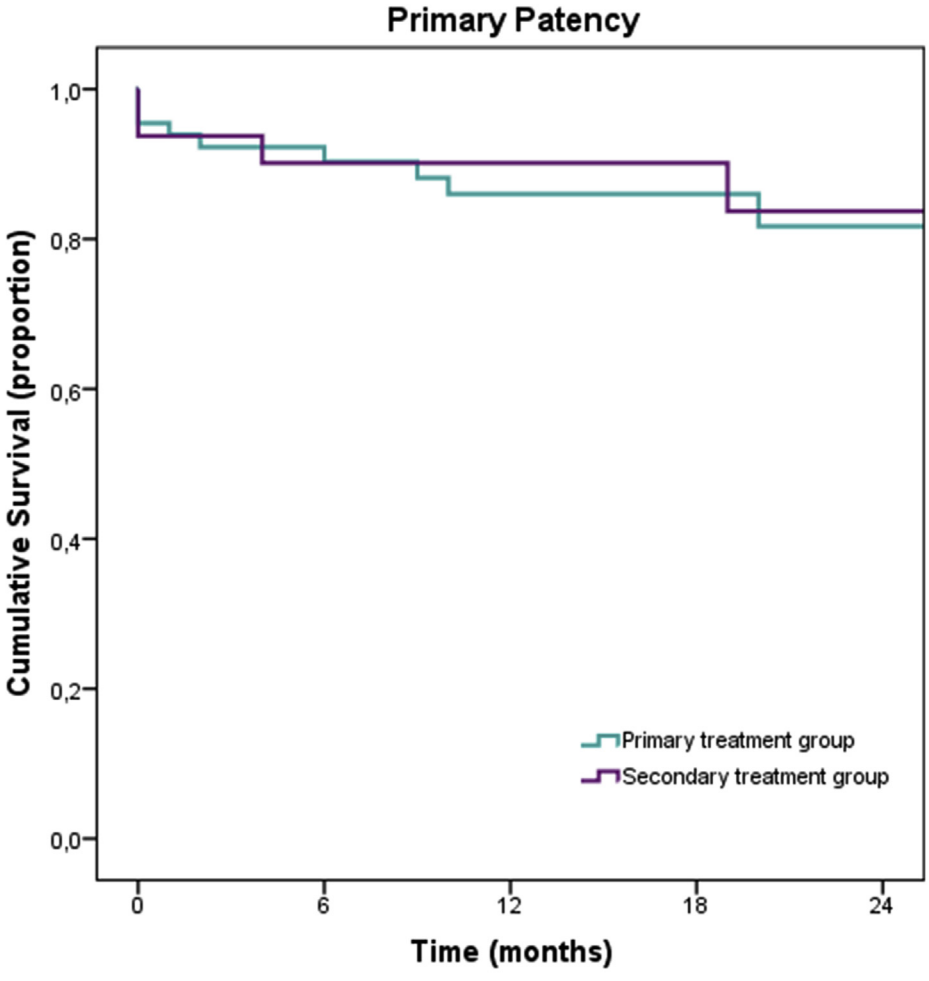
The mean ABI, measured bilaterally, significantly improved from 0.64 $\pm$ 0.21 before the procedure to 0.91 $\pm$ 0.14 after the procedure ($p < .001$). The highest measured ABI before the procedure improved from 0.71 $\pm$ 0.25 to 0.93 $\pm$ 0.14 after the procedure, measured using the same leg. Clinical improvement with at least one Rutherford category occurred in 89 of 96 patients (92.7%) at 6 months after the procedure. In the remaining three patients with technically successful CERAB no post-procedural Rutherford category was documented. The patients who did not improve included the patient with Rutherford 1, who was treated for a bypass at risk. One patient had no improvement because of a persistent dissection distal to the additional stent which was placed during the procedure. She was treated by further stent placement, 3 months after the CERAB procedure. Two patients had a stent collapse/severe kinking of one of the iliac stents at day 21 and day 30, respectively. One patient underwent kissing balloon PTA and the other patient converted to an aortic-bi-iliac surgical bypass as the patient

refused further endovascular treatment. One patient did not improve because of a short occlusion of the common femoral artery for which an endarterectomy was performed 5 months after the CERAB procedure. Another patient did not improve because of multiple stenoses in the superficial femoral artery for which balloon angioplasty was performed. In one patient, treated for severe claudication, the CERAB was extended to the external iliac artery for a stenosis distal to the stent after a month, without clinical improvement. The patient died before another re-intervention could be performed.

Patency rates

The primary patency rate at 6 months was 90.2%, at 1 year 87.3%, and at 2 years 82.3% (Fig. 2). At 6 months the secondary patency rate was 96.5%, 95.0% at 1 year, and 95.0% at 2 years (Fig. 2). Freedom from TLR was 92.4% at 6 months, 88.2% after 1 year, and 85.6% at 2 years (Fig. 2).

Univariate analysis showed no significant influence of smoking, diabetes mellitus, hypertension, dyslipidemia, renal disease, coronary artery disease, or carotid disease on the primary patency rates. There was no difference in the primary patency between patients treated for critical limb ischemia or intermittent claudication ($p = .90$). There was also no significant difference between patients who were primarily treated with CERAB and those who underwent previous intervention ($p = .44$) (Fig. 3). There were no differences in primary patency rate between the first 20 patients treated in each clinic, compared with the patients treated thereafter ($p = .33$).



Primary treatment					
No at Risk	66	47	32	21	17
Patency (%)	100	90.3	86.0	86.0	81.7
SE (%)	0	3.8	4.7	4.7	6.1
Previous treatment					
No at Risk	32	23	17	14	11
Patency (%)	100	90.1	90.1	90.1	83.7
SE (%)	0	5.4	5.4	5.4	8.0

Figure 3. Kaplan-Meier survival analysis showing primary patency curves of patients primarily treated with CERAB or CERAB following a previous intervention.

In 15 patients (15.3%) there was loss of primary patency during follow up. Ten patients had re-stenosis, of which three were caused by kinking of one of the iliac stents or stent collapse. These patients were treated by PTA and in one case by additional stent placement. The other seven patients developed a stenosis above the aortic stent ($N = 1$) or distal to the iliac stents ($N = 6$), referred to as edge stenosis. Two cases were not treated as the patients were symptom free, in three cases the iliac limb was extended with an additional CBES, and in the other two cases a PTA was performed. Five CERABs occluded, of which, one occurred after the patient stopped the anti-platelets. In two patients, treated with surgical thrombectomy and fibrinolysis, respectively, an outflow stenosis was found in the external iliac artery and treated by PTA in one case and an extra CBES in the other. In one patient there was a stent collapse of one of the iliac CBES. No cause was identified for the occlusion in the last patient. The latter two were treated with a surgical bypass. Loss of primary patency occurred in nine patients within the first 6 months of the procedure and in two patients after 2 years. The limb salvage rate was 100%.

DISCUSSION

In this study the first results of the CERAB technique are presented, which confirm the safety and efficacy of this new endovascular approach for extensive and complex occlusive lesions of the aortic bifurcation. To date, surgical reconstruction has been the gold standard for the treatment of TASC-II C and D lesions according to the TASC-II guidelines.[1] By mimicking the aortic bifurcation anatomically and physiologically, CERAB might improve the patency rate of endovascular techniques and also reduce the risk of severe complications when compared with surgical reconstruction. The technique may be a valid alternative to current treatment modalities.

Calculated primary patency rates of the CERAB procedure in this study cohort are 87.3% at 1 year and 82.3% at 2 years. These primary patency rates appear to be at the same level as have been described for kissing stents. However, many patients in the present study, in contrast with the kissing stent series, were treated for the more complex TASC-II D lesions. The published kissing stent series usually consist of mixed populations treated for all TASC lesions and treated for different indications. In a recent review, it was shown that the indications for treatment with kissing stents varied greatly, from 33% to 100% of patients treated for claudication.[20] In the present study 36.9% of the patients were treated for critical limb ischemia. In addition, the incidence of TASC A and B lesions treated with kissing stents varied from 0% to 92%, rendering comparisons unfair with the present group of patients, who were mostly treated for TASC-II D lesions. Another point of interest is the definition of loss of primary patency used. This study used a definition that included re-stenosis, as was also used by Sabri et al. in their historical cohort study on kissing covered stents.[8] This is in contrast with the outcomes presented by Humphries et al., where primary patency was only affected by stent occlusion or re-interventions.[21] In the present authors' opinion, re-stenosis is an important outcome of endovascular procedures and should be taken into account, as Diehm et al. have suggested.[18]

Re-interventions performed to improve or preserve outflow will decrease primary patency rates. As two patients developed occlusions based on outflow impairment, the present authors advocate treatment of stenosis in the iliac tract aggressively to prevent occlusions. This may lead to an increased incidence of re-interventions, even in the absence of symptoms. Secondary patency rates were excellent, 95.0% at 2 years. This implies greater durability of CERAB when preventive re-interventions are performed. In examining re-interventions performed for clinical symptoms (e.g. freedom from TLR), patency rates were 88.2% at 1 year and 85.6% at 2 years.

Loss of primary patency was affected by three major causes. The first and most important reason was stenosis resulting in outflow obstruction. This emphasizes that it is essential to cover the entire stenotic area, with special attention to the distal end before deployment. Otherwise the atherosclerotic lesion may advance distally, resulting in an edge stenosis. The present authors advocate covering the disease from healthy to healthy areas, although intimal disease will always be present in atherosclerosis. Second, four cases of stent collapse or kinking of the iliac tract were observed. In three cases the collapse was situated at the point of crossing of the iliac stents, at the level of the cuff of the aortic stent, thereby pointing at a weakness of the present technique. Another collapse occurred in a 6 mm stent distal to the aortic cuff, at the origin of the native iliac artery. It is possible that highly calcified lesions overcome the radial force of the CBES, especially in small diameters, and improvement in stent design could be used to solve this problem. One patient had an occlusion possibly related to poor therapy compliance. This underlines the importance of the use of anti-platelet or anti-coagulation therapy. In the present study protocol, all patients were treated with anti-platelet therapy, including clopidogrel during the first 6 months and lifelong acetyl salicylic acid (with the exception of patients treated with anti-coagulants such as acenocoumarol or warfarin for other indications). In a high flow reconstruction, however, single anti-platelet therapy might be adequate, but no scientific argument is provided for this in this first case series.

In the present study all patients were included from February 2009 to March 2014. As patency curves did not differ significantly after the treatment of 20 patients, a learning curve was not found to be a factor that affected the results. One would expect that with growing experience results would improve, however, with growing experience the indication for CERAB was expanded in both hospitals to patients with more and more complex lesions, which could possibly have affected results negatively, thereby hiding a learning curve effect. The effect of experience is shown in a patient who underwent a successful CERAB procedure, 2 years after an initial failure. In both clinics, an endovascular

first strategy is now applied and surgical bypass grafting is reserved for those patients in whom a CERAB cannot be performed. Now, no patients are excluded for CERAB based on pre-operative imaging. Nevertheless, in very complex lesions in low risk patients, open surgery is always considered. The kissing stent technique has mostly been abandoned.

When treating an occlusion it may be difficult to determine whether the guidewire is advanced intraluminally or subintimally, but as the entire lesion is covered with CBES, this is not clinically relevant. Re-entry to the vascular lumen is always made as distal as possible in the patent aorta. When renal arteries or even visceral arteries are involved in the diseased segment, the use of protective balloons or chimney grafts may be considered.

One of the advantages of the use of CBES is that it might prevent or immediately treat procedural complications such as rupture and distal embolization. There were no clinical signs of distal embolization in the present series. The two ruptures that occurred during procedure were both treated endovascularly, one with the CERAB itself. Other complications during the procedure could all be treated endovascularly, without clinical consequences for the patient making the procedure extremely safe. Patent lumbar collaterals may be occluded by the covered stents, but in the present cohort no patients had symptoms of spinal cord ischemia.

Two major complications occurred for a major complication rate of 1.9%. In one patient, pre-operative impaired renal function worsened after treatment, ultimately leading to hemodialysis after 1 year. This underlines the importance of peri-operative measures to reduce the risk of contrast induced nephropathy. The other major complication consisted of a bilateral pneumonia. This patient was admitted from the department of cardiology and was deemed unfit for a surgical bypass procedure because of cardiac and pulmonary comorbidity. After 3 days of post-procedural observation in the ICU, he was re-admitted to the department of cardiology where he developed a bilateral pneumonia. Eventually the patient died 5 weeks after the procedure. This demonstrates the vulnerability of this group of patients. Most of the observed complications in the present cohort were minor hematomas in the groin. In cases of percutaneous access two types of closure devices were used, but the significance of this cannot be assessed as it was not in the scope of the present study. The close observation of the present population treated with a new technique, also reflected by the high ICU admission in the early experience, may explain the relatively high incidence of hematomas. Overall, CERAB seems to be associated with a lower major morbidity rate compared with surgical reconstruction, but this should to be established in a randomized trial.

CBES are more expensive than bare metal stents and therefore the cost-effectiveness of the CERAB procedure is unclear and needs to be addressed. The need for re-interventions may even increase costs in the long term. However, the low morbidity and mortality compared with surgical repair also reduces costs with regard to in hospital and ICU stay. Moreover, the long-term morbidity of surgical repair, including incisional hernia and adhesion formation with the risk of small bowel obstruction, is accompanied by high costs as well, but these are often neglected. With CERAB the in hospital stay is short with a median hospital stay of 2 days. The first patients treated were observed post-operatively in the ICU according to the protocol of aortic bifurcation reconstructions. Meanwhile, the protocol has changed for endovascular reconstructions. Therefore, the 20.3% ICU admission appears to be a large overestimation of the need for close hemodynamic observation. Observation at a so called medium care facility could provide an alternative; however, one of the hospitals included in this study does not have such a unit. From the last 60 patients treated, only nine were observed in the ICU, for cardiac or pulmonary reasons. Given the low morbidity rate, treatment on an outpatient basis could be justified. It may be possible to abandon the annual duplex ultrasound when the technique has proved its safety in the long term.

This study is limited by being retrospective, therefore the results are likely to be affected by selection bias. Some data are lacking, such as the occurrence of symptoms of buttock claudication or erectile dysfunction after the procedure, which could not reliably be retrieved from the databases. Furthermore, follow up of 2 years was not completed for the entire cohort. The standard error of estimated patency rates at 2 years was 4.9%, confirming the reliability of the calculated patency rates. This study presents the first world experience with the CERAB technique, and long-term data are required before the technique can be considered the new standard.

A randomized controlled trial with prolonged follow up to compare surgical bypass procedures, the kissing stent technique, and CERAB for TASC-II D lesions is indicated to compare morbidity, outcome, and cost-effectiveness. The feasibility of such a study is low however, because of the relatively low incidence of these lesions and as the co-morbidity in many patients could drive the physicians towards an endovascular preference, to reduce morbidity and mortality.

CONCLUSION

The CERAB technique is a safe and feasible alternative to open surgical reconstruction of the aortic bifurcation in complex AIOD. Comparative studies with the current gold standards are indicated to define the role of this technique in the treatment algorithm of TASC-II C and D lesions. Critical issues include long-term patency rates, cost-effectiveness, patient selection, fine tuning of the technique, and definition of optimal medical support.

CONFLICT OF INTEREST

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